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100 WATT THERMOELECTRIC GENERATOR

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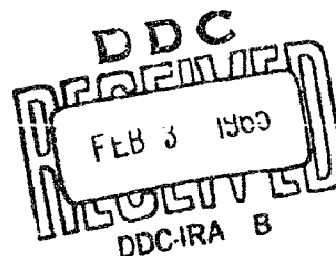
U.S. ARMY ELECTRONICS LABORATORY

FORT MONMOUTH, NEW JERSEY

CONTRACT NO. DA 28-043 AMC-00265 (E)

ORDER NO. FR 28 043-M 4-35028 (E)

PROJECT NO. IE 6 41029 D 535 12



Thermoelectric Products Engineering, Direct Energy Conversion Department
ELECTRONIC COMPONENTS AND DEVICES
RADIO CORPORATION OF AMERICA HARRISON, NEW JERSEY

100 WATT THERMOELECTRIC GENERATOR

Report No. 1

Covering Period: July 1, 1964 to Sept. 30, 1964

Contract No. DA28-043-AMC-00265(E)

Order No. FR 28 043-M4-55028(E)

Objective: The objective is to develop an exploratory type thermoelectric generator, operated on leaded gasoline, that delivers 100-watts and 12 volts.

Prepared By:

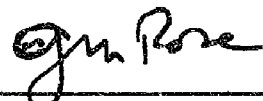


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1. PURPOSE

The purpose of this program is to design, construct and test an exploratory model 100-watt thermoelectric generator which uses leaded gasoline as its fuel. The generator, when developed, will provide 100-watts of output power with a voltage output of 12 ± 2 volts. This power source should be silent in operation and capable of at least 1000 hours of operation without major maintenance or replacement of parts.

2. ABSTRACT

The dimensions of the silicon-germanium thermocouples, and subsequently, of the power modules have been determined. The thermoelectric converter, to be constructed from these power modules, will operate at a hot junction temperature of 885°C and a cold junction temperature of 150°C. The cold shoe temperature will be maintained by the use of forced convection cooling.

The thermoelectric converter will consist of twelve power modules each having six thermocouples. Forced convection cooling of the cold shoes will be accomplished through the use of two centrifugal fans and heat exchangers. The heat exchangers are commercially available and have been ordered.

Thermocouples and parts for the power modules are being fabricated, and the generator housing is being assembled.

Several types of burners were considered for the thermoelectric generator, but a vaporizing-type radiant burner, in development at RCA, was selected. This burner consists of a radiant, burner head, injector and vaporizer section, all of which have been designed during this quarter. All parts of the burner head and injector have been constructed as have most of the parts of the radiant and vaporizer sections. The completed parts of the burner are being assembled in preparation for the evaluation test program.

The selection of the auxiliary components and control devices and the design of the generator assembly have not been completed yet since the thermoelectric converter assembly and burner design have not been fully evaluated.

3. CONFERENCES

On Sept. 3, 1964, Mr. G. Hunrath of the U.S. Army Electronics Laboratories met with Messrs, G. M. Rose, O. H. Schade, Jr. and H. P. Van Reyst, at RCA, to discuss the progress being made on the contract. In this discussion, agreement was reached on modifications in the dimensions of the power module over those of the module developed under Contract DA-36-039-AMC-00110(E). The expected results are improved module reliability and lower ultimate cost.

4. FACTUAL DATA

To accomplish the goal of this program, the effort has been divided into four major phases:

- 1) Design and construction of a thermoelectric converter unit utilizing the "building-block" modules developed by RCA for the U.S. Army Electronics Laboratory under Contract No. DA-36-039-AMC-00110(E).
- 2) Design and construction of a burner unit which will operate on the vaporizing principle and will utilize leaded gasoline as its fuel.
- 3) Selection of various auxiliary components and control devices required, including their purchase or construction.
- 4) Integration of the converter, the burner and the auxiliary components into a complete exploratory generator system.

The work carried out under each of these phases, during this quarter, is described in the following sections.

4.1 Thermoelectric Converter Design

The design of the thermoelectric converter is based on the use of the six-couple power module construction developed by RCA under contract No. DA-36-039-AMC-00110(E). The thermoelements to be used are those of the earlier contract. It is planned, however, to use an improved hot shoe material developed by RCA since the earlier contract. This silicon alloy has been shown to give improved efficiency, better bond stability, and longer life expectancy.

The thermocouple life performance demonstrated on the earlier contract, and RCA's subsequent experience, has shown no need for series-parallel interconnections of thermocouples as a reliability measure. The present generator will therefore use series interconnections, requiring

half the number of thermocouples and resulting in a substantial reduction in ultimate generator cost.

To avoid the use of relatively large and heavy cooling fins to reject the waste heat, forced air cooling will be used. A blower of adequate size for the thermoelectric converter will require nearly 20 watts of power. Therefore, the total output of the generator must be 120 watts. The detailed design calculations for the converter follow.

4.1.1 Converter Calculations

The surface temperature of the hot shoe is to be 900°C, with a temperature drop through the shoes of 15°C. Thus, the hot junction temperature will be 885°C. Using a centrifugal blower and assuming an ambient temperature of 50°C, the cold junction temperature can be maintained at 150°C.

For these operating temperatures, the following thermoelectric parameters are known.

α_N	- average Seebeck coefficient, N-element	= -280 $\mu\text{V}/^\circ\text{K}$
α_P	- average Seebeck coefficient, P-element	= 196 $\mu\text{V}/^\circ\text{K}$
ρ_N	- average resistivity, N-element	= 2.96 m Ω cm
ρ_P	- average resistivity, P-element	= 1.75 m Ω cm
K_N	- average thermal conductivity, N-element	= 0.039 watts/cm $^\circ\text{K}$
K_P	- average thermal conductivity, P-element	= 0.041 watts/cm $^\circ\text{K}$
τ_N	- average Thomson coefficient, N-element	= -167 $\mu\text{V}/^\circ\text{K}$
τ_P	- average Thomson coefficient, P-element	= 109 $\mu\text{V}/^\circ\text{K}$

The voltage output to a matched load ($R_L = R_{\text{internal}}$) for a couple is

$$E_L = \frac{(\alpha_N + \alpha_P) \Delta T}{2} = \frac{(280 \times 10^{-6} + 196 \times 10^{-6}) 735}{2} = 0.175\text{V}$$

With a total voltage of 12 volts required, the number of couples will be:

$$N = \frac{12}{0.175} = 69$$

Utilizing the 6 couple modules, the generator will incorporate 12 modules or 72 couples connected in series, giving a total converter voltage output (E_L) of $72 \times 0.175 = 12.6$ volts.

With a total power output (P_o) requirement of 120 watts,

$$P_o/\text{couple} = \frac{120}{72} = 1.67 \text{ watts}$$

$$I_L = \frac{P_o}{E_L} = \frac{120}{12.6} = 9.6 \text{ amp.}$$

$$R_L = \frac{E_L}{I_L} = \frac{12.6}{9.6} = 1.32 \Omega$$

or

$$R_L/\text{couple} = \frac{1.32}{72} = 0.0184 \Omega$$

Laboratory measurements have shown that the resistance of the contacts and of the hot shoe amounts to approximately 15 percent of the total couple resistance. Therefore, the resistance of the thermoelectric pellets is

$$R_{TE} = 0.85 \times 0.0184 = 0.0156 \Omega/\text{couple},$$

and the ratio

$$\frac{L}{A} = \frac{R}{\rho_N + \rho_P} = \frac{0.0156}{(2.96 \times 10^{-3} + 1.75 \times 10^{-3})} = 3.33 \text{ cm}^{-1}$$

A pellet length of 1.65 cm was selected in an attempt to minimize

shunt losses. Using this pellet length

$$A = \frac{1.65 \text{ cm}}{3.33 \text{ cm}^{-1}} = 0.492 \text{ cm}^2$$

With these dimensions known the couple dimensions can be established, as shown in Figure 1.

4.1.2 Heat Input

The heat input into the converter can be calculated by determining the heat conducted through the active elements, the heat required to balance the Peltier effect, and the Joule and Thomson heating effects, as follows:

$$\mathcal{Q}_{\text{input}} = \mathcal{Q}_1 + \mathcal{Q}_2 - \mathcal{Q}_3 + \mathcal{Q}_4$$

where:

\mathcal{Q}_1 = heat conducted to the cold junction through the elements.

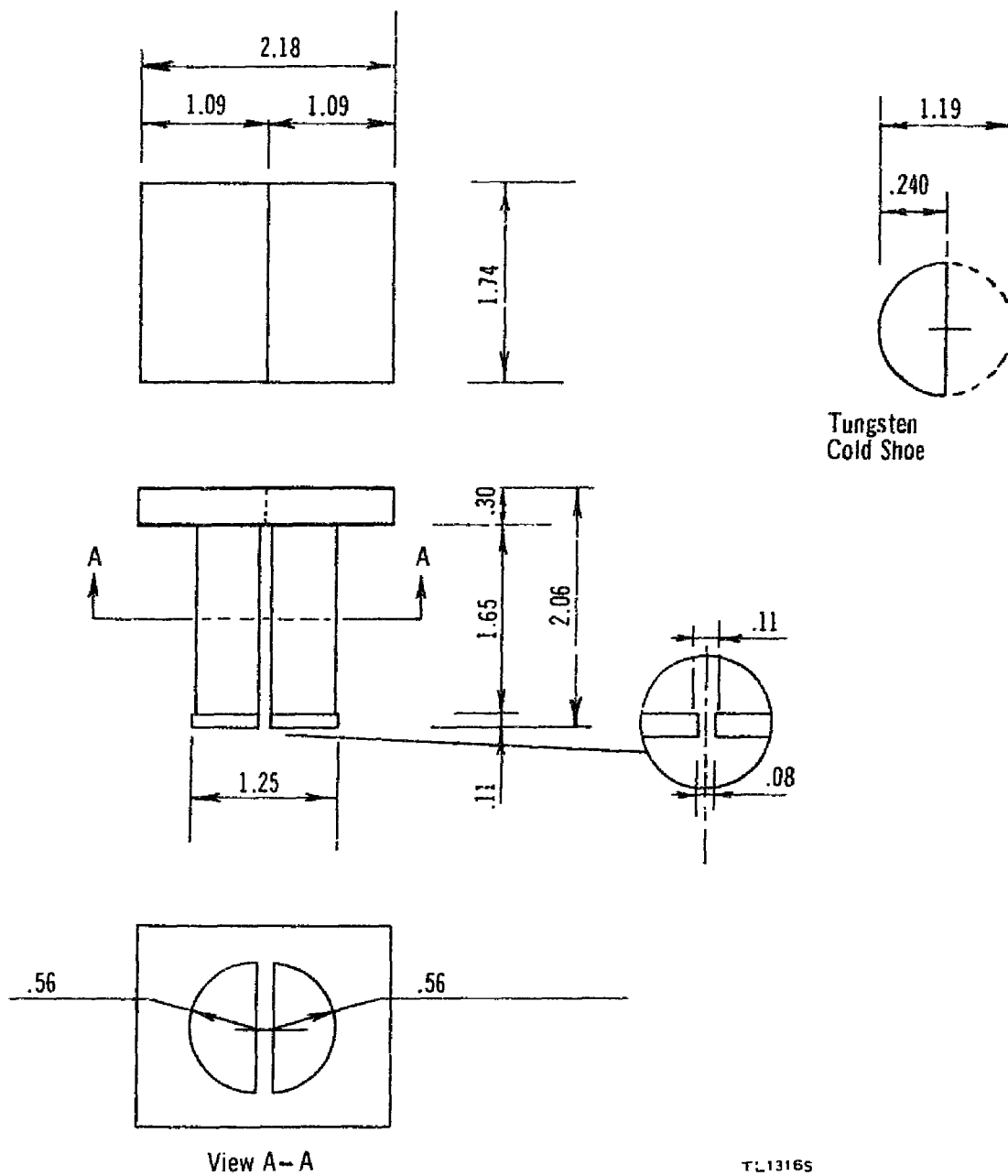
$$\begin{aligned} \mathcal{Q}_1 &= N (K_N + K_P) \frac{A}{L} (T_H - T_C) \\ &= 72 (.039 + .041) \frac{1}{3.33} \times 735 = 1275 \text{ watts} \end{aligned}$$

\mathcal{Q}_2 = heat supplied to balance the Peltier effect at the hot junction.

$$\begin{aligned} \mathcal{Q}_2 &= N (\alpha_N + \alpha_P) I_L T_H \\ &= 72 (280 \times 10^{-6} + 196 \times 10^{-6}) 9.6 \times 1160 = 382 \text{ watts} \end{aligned}$$

\mathcal{Q}_3 = one half the Joule heating effect in the elements conducted to the hot junction.

$$\mathcal{Q}_3 = \frac{1}{2} I_L^2 R_L$$



All Dimensions in cm

FIGURE 1 SCHEMATIC DIAGRAM OF SILICON-GERMANIUM THERMOCOUPLE

$$= \frac{1}{2} 9.6^2 \times 1.32 = 61 \text{ watt}$$

q_4 = one half the Thomson heat generated in the thermoelements and conducted to the cold junction.

$$\begin{aligned} q_4 &= \frac{1}{2} N (T_N + T_P) I_L (T_H - T_C) \\ &= \frac{1}{2} 72 (167 \times 10^{-6} + 109 \times 10^{-6}) 9.6 \times 735 = 70 \text{ watt} \end{aligned}$$

Therefore, the total heat input absorbed by the power modules is

$$q_{\text{input}} = 1275 + 382 - 61 + 70 = 1666 \text{ watts}$$

Assuming a shunt loss of 15 percent,

$$q_{\text{total}} = 1666 \times 1.15 = 1920 \text{ watts.}$$

4.1.3 Heat Flux Density

The heat flux density through the "half-cylinder" pellets, will be

$$F_P = \frac{1920}{2 \times 72 \times 0.492} = 27 \text{ watts/cm}^2$$

The heat flux density through the hot shoes will be

$$F_{HS} = \frac{1920}{72 \times 0.860 \times 0.685 \times 6.45} = 7 \text{ watts/cm}^2$$

The burner mantle, having a surface of 240 cm^2 has a flux density of;

$$F_M = \frac{1920}{240} = 8 \text{ watts/cm}^2$$

4.1.4 Heat Rejection

As stated previously, the thermoelectric converter will

utilize forced convection cooling. A commercially available heat exchanger, made by Pin Fin Incorporated, is being evaluated for this purpose. The exchanger, which is made of aluminum, consists of 1.90 cm long pins brazed into a housing. The packing density of the pins is 12.5 per square cm. The total radiator surface available with this heat exchanger is 530 square cm. Having 530 square cm of radiator surface available and assuming an ambient temperature (T_{amb}) of 50°C and an average radiator temperature (T_{rad}) of 120°C (30°C temperature drop from cold junction to radiator), the unit heat rejection rate is:

$$q_{rej} = \frac{q_{total}}{A_{rad} (T_{rad} - T_{amb})} = \frac{1920}{530 (120 - 50)} = 0.052 \text{ watts/sq.cm/}^{\circ}\text{C}$$

Based on the information supplied by the Pin Fin Corporation, for the above described heat exchanger bolted to the heat source with a silicone grease layer between the interface, and a heat rejection rate of 0.052 watts/sq. cm/°C, the airflow, $V = 9.7$ cubic cm/min per cm face width and the pressure drop $\Delta P = 0.06$ cm H_2O /cm.

Since the total available face width is 38 cm and the height of the exchanges is 19 cm.

$$V_{total} = 38 \times 9.7 = 368 \text{ cubic cm/min. (22.5 CFM)}$$

$$\Delta P_{total} = 19 \times 0.06 = 1.14 \text{ cm } H_2O \text{ (0.42 inch } H_2O)$$

Two centrifugal blowers connected in parallel on a common motor will be required to obtain this airflow and pressure drop. The motor (Globe MM-3) will operate on 12 volts DC and will require approximately 15 watts input.

4.1.5 Converter Assembly

The thermoelectric converter consists of 12 power modules

(see Figure 2) assembled into an aluminum hexagonal frame.

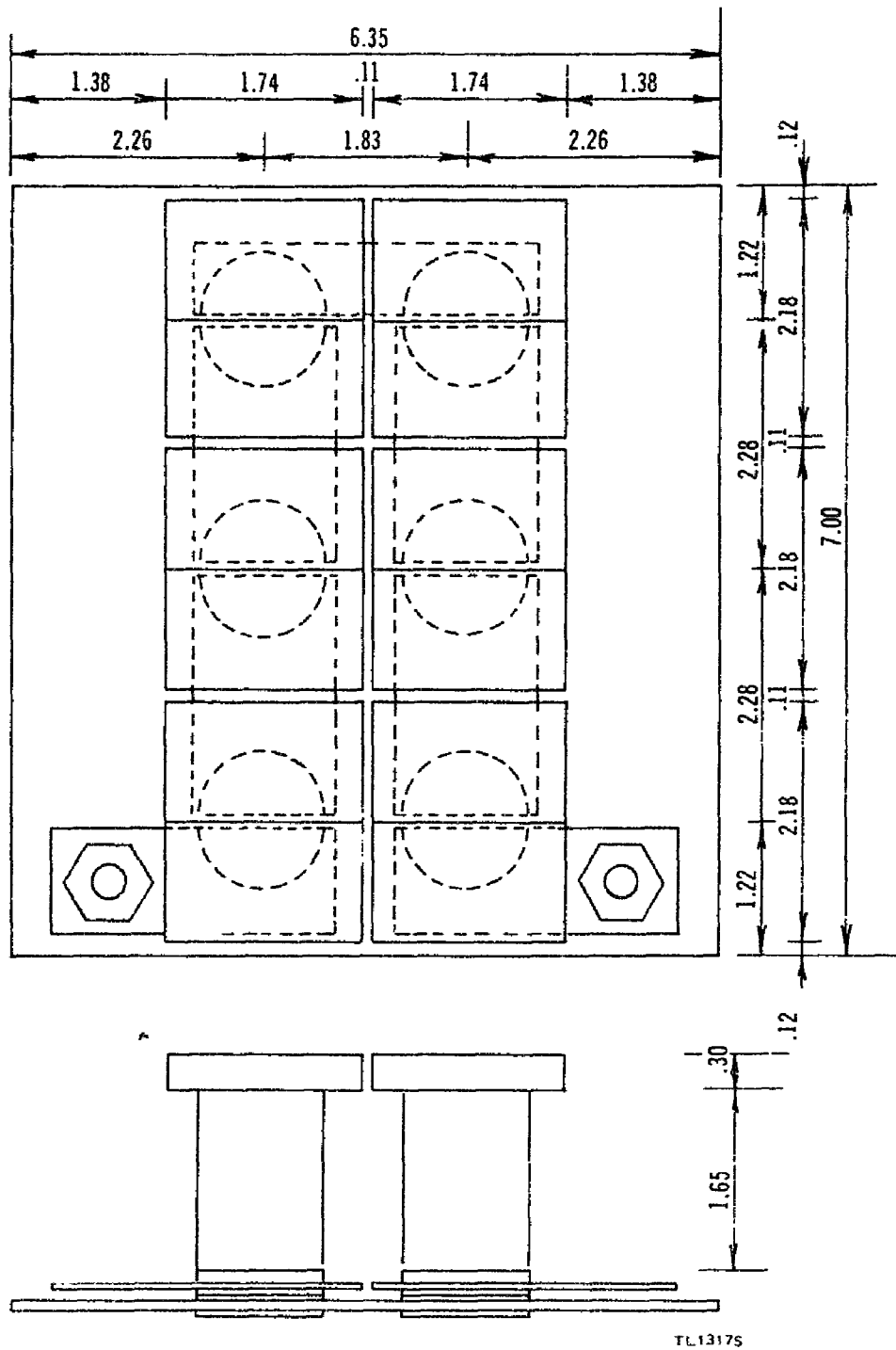
A plenum is mounted on the base of this frame to distribute the cooling air uniformly. Figure 3 shows the construction of the converter housing the plenum, the blowers and the location of the burner.

4.2 Design of the Liquid-Fuel Burner

4.2.1 Introduction

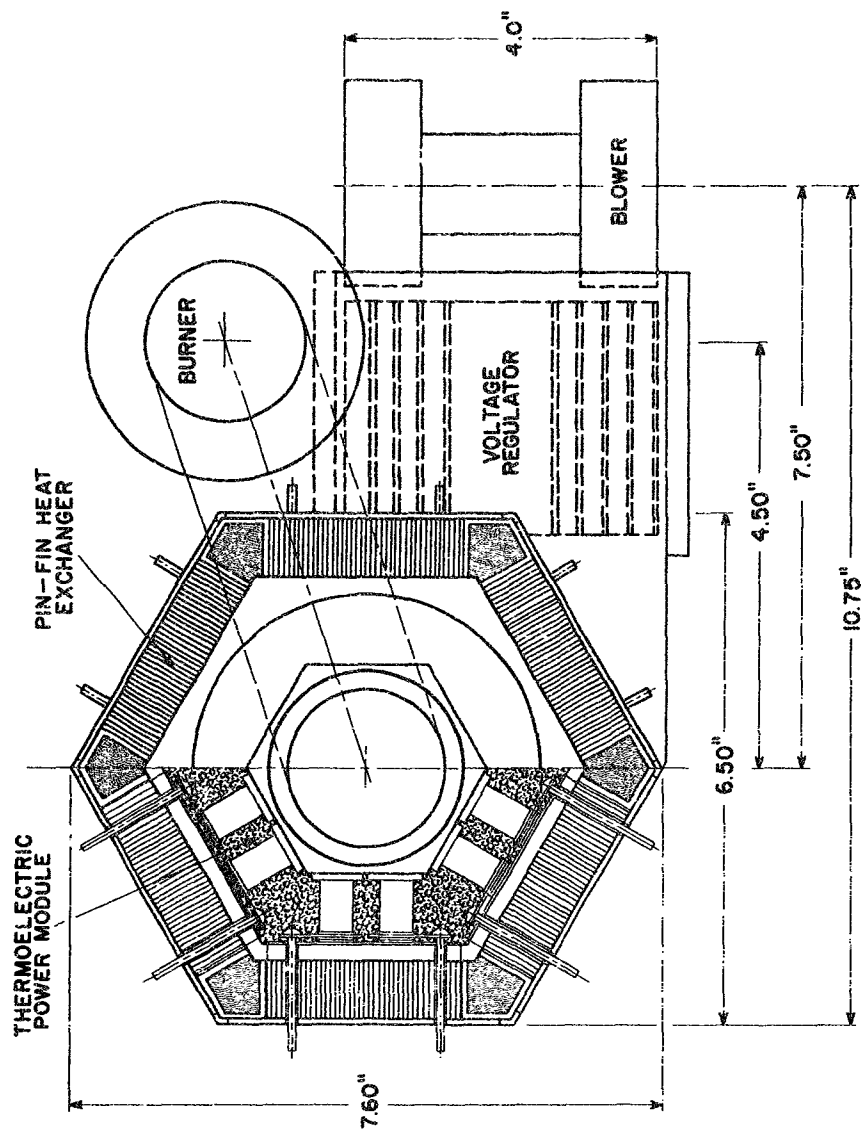
The leaded-gasoline burner being developed for the 100-watt thermoelectric generator is of the vaporizing type (see Figure 4). In this type of burner, vaporized fuel flows at high velocity through a small orifice and entrains all the required combustion air in a compound injector. The injector supplies the fuel-air mixture through a stabilizing gridwork to the combustion zone within a porous metal radiant. The radiant abstracts considerable energy from the hot combustion gasses and radiates to the 900°C thermoelement hot-shoes. Waste exhaust gasses are routed through a heat exchanger affixed to the fuel vaporizer. It will be necessary to maintain the vaporizer temperature within a rather narrow range; hence, a control system is required. The most practical system appears to be a mercury-actuated plunger and butterfly-valve.

It is expected that the burner will require starting techniques similar to those of a liquid-fuel torch. A starting burner is used to heat the vaporizer, which must be up to temperature before the generator heating cycle can be initiated. Starting in extreme cold will probably require that the burner "plumbing" (injector and mixture piping) be given a moderate preheat so that excessive fuel condensation does not occur. It is planned to accomplish these functions with the starting burner within about three minutes time.

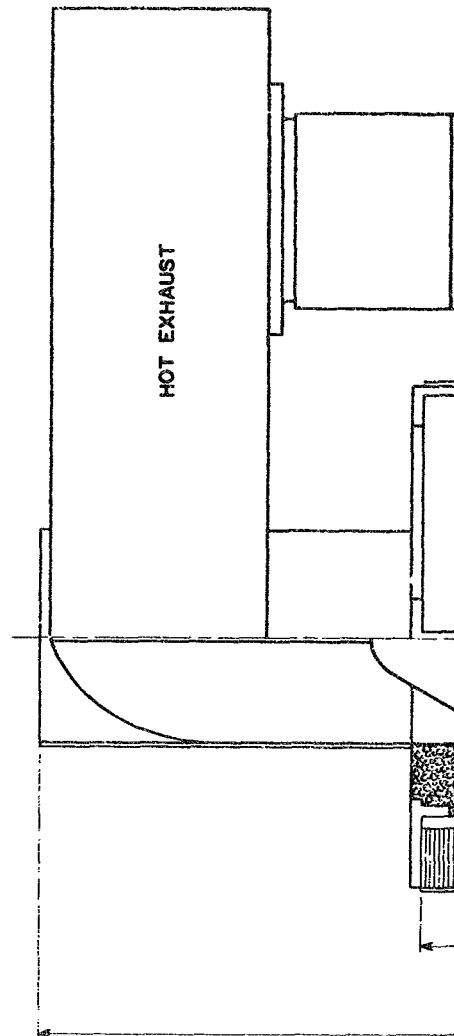


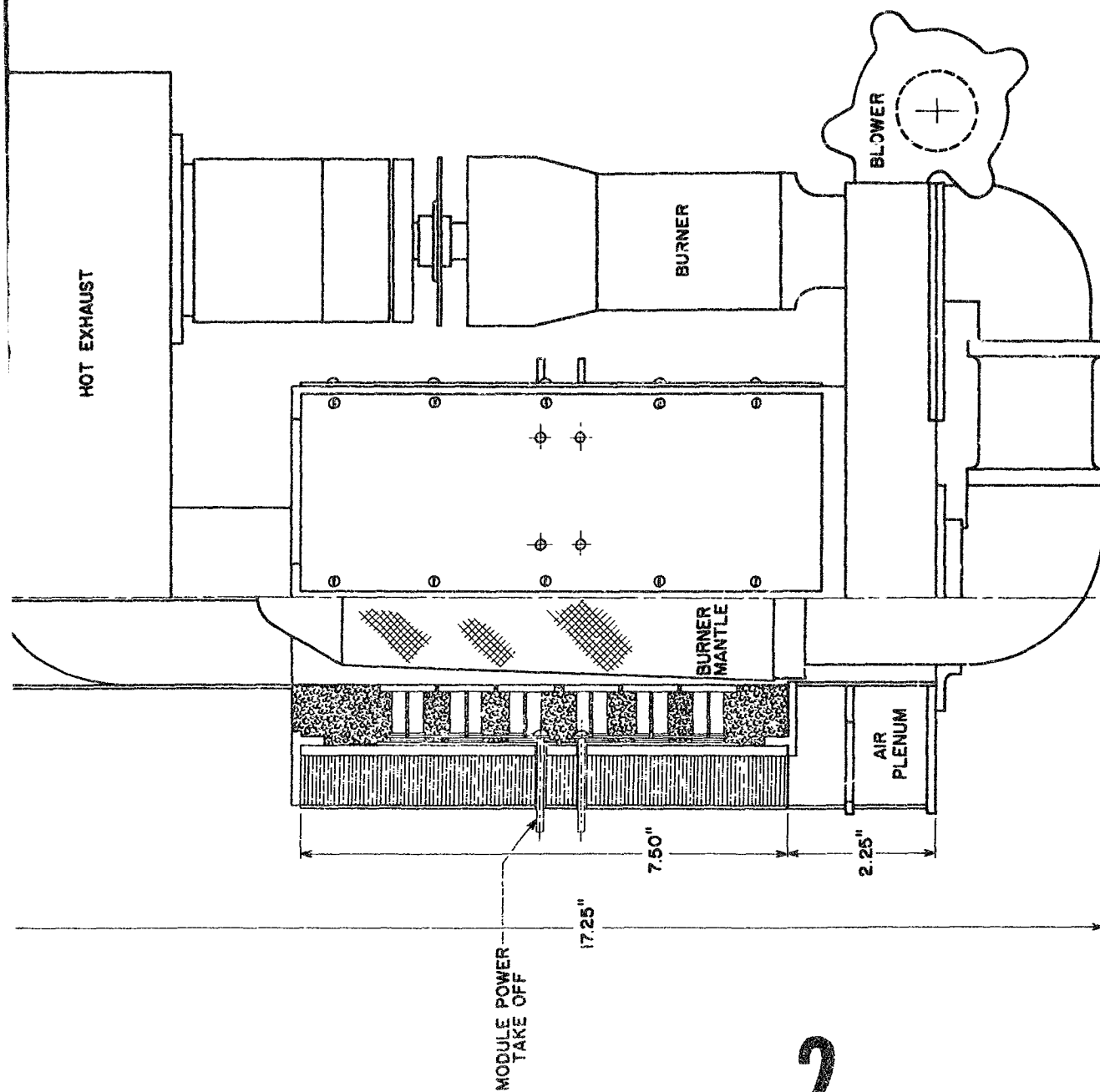
All Dimensions In cm

FIGURE 2 SCHEMATIC DIAGRAM OF THERMOELECTRIC POWER MODULE



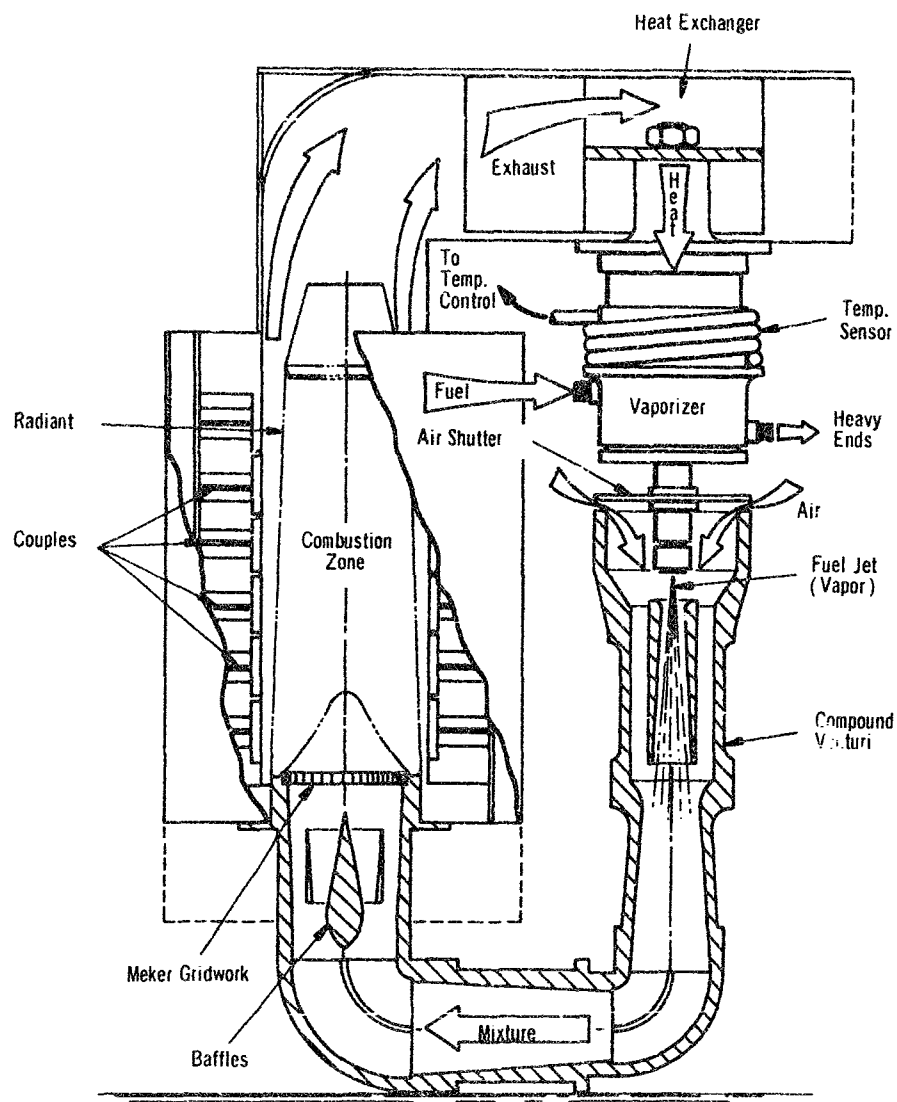
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2

FIGURE 3
100 WATT THERMOELECTRIC GENERATOR
POWER MODULES, AIR SYSTEM AND BURNER ARRAY



TL13155

FIGURE 4 SCHEMATIC DIAGRAM OF BURNER SYSTEM

The following sections will describe the burner requirements, design, operating characteristics and status in greater detail. It will become apparent that the major engineering effort will be required to produce a practical burner that can be started in environmental extremes. The techniques of vaporization and quiet, efficient combustion have already been proven in RCA-developed prototypes.

4.2.2 Burner Requirements

Several major requirements must be met by the burner:

- 1) Good combustion efficiency.
- 2) Proper distribution of heat supplied to the thermoelements.
- 3) Stable and quiet combustion.
- 4) Ease of starting and operation in environmental extremes (preferably, without auxiliary power source).
- 5) Ability to burn leaded gasoline with minimum service requirements.

Several types of burners have been considered for this application, but the choice was eventually narrowed down to a vaporizing-type radiant burner in development by RCA. The reasons for choosing this type of burner are:

- 1) Thousands of hours of trouble-free service with gaseous-fuel prototypes. These burners have proven the suitability of the (predominantly) radiant mode of heat transfer, and provided design techniques for obtaining efficient, stable, quiet combustion with heat loads at 900°C.
- 2) All combustion air is entrained in an atmospheric injector. Neither blower nor starting battery is required, and the injector will supply all combustion air

in the fuel-air premix.

- 3) Proven combustion efficiency at the relatively high temperatures at which silicon-germanium thermoelements operate. Layout of generator parts, thermal insulations and the art of radiant construction have been developed for the gaseous radiant burner. Techniques are virtually identical for the vaporized-fuel burner.
- 4) The successful development of a leaded-gasoline prototype burner. RCA has obtained stable, service-free operation with an electrically-heated vaporizer for eight-hour periods totaling in excess of 100 hours.

It is tempting to consider the use of an ultrasonic atomizer, such as developed by Young, Wilson and Lang of Esso Research,¹ since relatively long life is promised with several different fuels. However, a suitable burner utilizing the ultrasonic atomizer is not currently available, and preliminary tests made at RCA (with an API-sponsored atomizer), though encouraging, indicate that considerable engineering will be required to approach the noise-levels currently achieved with the vaporizing burner. It is necessary, for example, that fuel be in the vapor state if a flame-front stabilizer is employed in the mixture stream. In addition, the oscillator and combustion-air blower present a continuous power-drain of about 10 watts, and a starting battery is required.

Several other interesting developmental burners have been described in the literature, notably in the API Proceedings of recent years, but virtually all are intended for higher firing-rates and/or appear, by design, to be relatively noisy.

It is the opinion of RCA that a simple vaporizing burner will not perform satisfactorily. If, in subsequent descriptions of the vaporizing burner it appears to be overly complex, comparison with light-oil vaporizer construction in a text such as, "Industrial

Furnaces" by Trinks² will show that the required vaporizer functions are accomplished by relatively simple means. The point to be made is that complexity need not imply low reliability. In this case, the functions performed in the vaporizer are deemed essential to good operation. On the other hand, it should be recognized that some cracking of the hydrocarbon fuel is liable to occur in any vaporizing system,² and that vaporizer cleaning will eventually be necessary. In addition, the tetraethyl-lead additive in the gasoline can cause a lead-salt accumulation in the flame-stabilizing gridwork, should the burner be improperly adjusted. Therefore, a conscientious operator will obtain a service-life performance superior to that obtained by unconcerned personnel.

4.2.3 Description of Burner Design

4.2.3.1 Fuel Supply

The leaded gasoline will be stored in a fuel container having a volume somewhere between 2-1/2 and 4 gallons. A nominal firing-rate of 17,900 BTU/HR is anticipated for 120 watts gross generator output. The fuel consumption rate is, therefore, 0.957 lbs. per hr., and the required volume for an eight-hour mission³ is 1.33 gallons (2.92 cu. cm). Fuel pressures at the vaporizer orifice of 15-25 psig are anticipated. A fuel-tank pressure of 30-40 psig will be obtained with a hand pump at generator startup. A regulator should hold orifice pressure essentially constant for eight hours. Should longer missions be desired, more gasoline could be carried in the tank, but an additional pumping would be required during the mission.

The fuel type is limited to leaded gasolines. Although it may be feasible to vaporize kerosene JP-1, JP-3 and JP-4 in practical burners, vaporizer temperatures in

excess of 250°C would be needed. Life data is not available at these temperatures, vaporizer designs would be changed, and practical problems such as gasket materials would need re-evaluation.

4.2.3.2 The Vaporizer

The vaporizer is shown in greater detail in Figure 5. Heat enters the vaporizer at the top and is conducted down the outer walls of the first-effect. Here, most of the gasoline is vaporized in a nucleate boiling mode in the revolver-like cylinder bores. Vapor and fuel droplets are sprayed into a central annular "settling" chamber, where the "heavy ends" are mechanically separated and drain into the float chamber, to be discharged when a sufficient quantity has accumulated. These "heavy ends" contain substantial amounts of the smoky-burning and coke-forming aromatics, as well as some tetraethyl lead. The vapors rise toward the heat inlet, and are superheated in the central tube to assure high-quality vapor, which passes through the orifice at the bottom of the superheater.

The vaporizer shown differs from its successfully-tested prototype in several aspects:

- 1) The vaporizing rate has been scaled upward by a factor of 4:1.
- 2) A single heat-source is employed for both first-effect and superheater; a conduction gradient is impressed where heat enters the first-effect, to depress its temperature.
- 3) A coaxial construction around the super-heat tube should reduce shunt heat-losses and minimize the tube gradient.

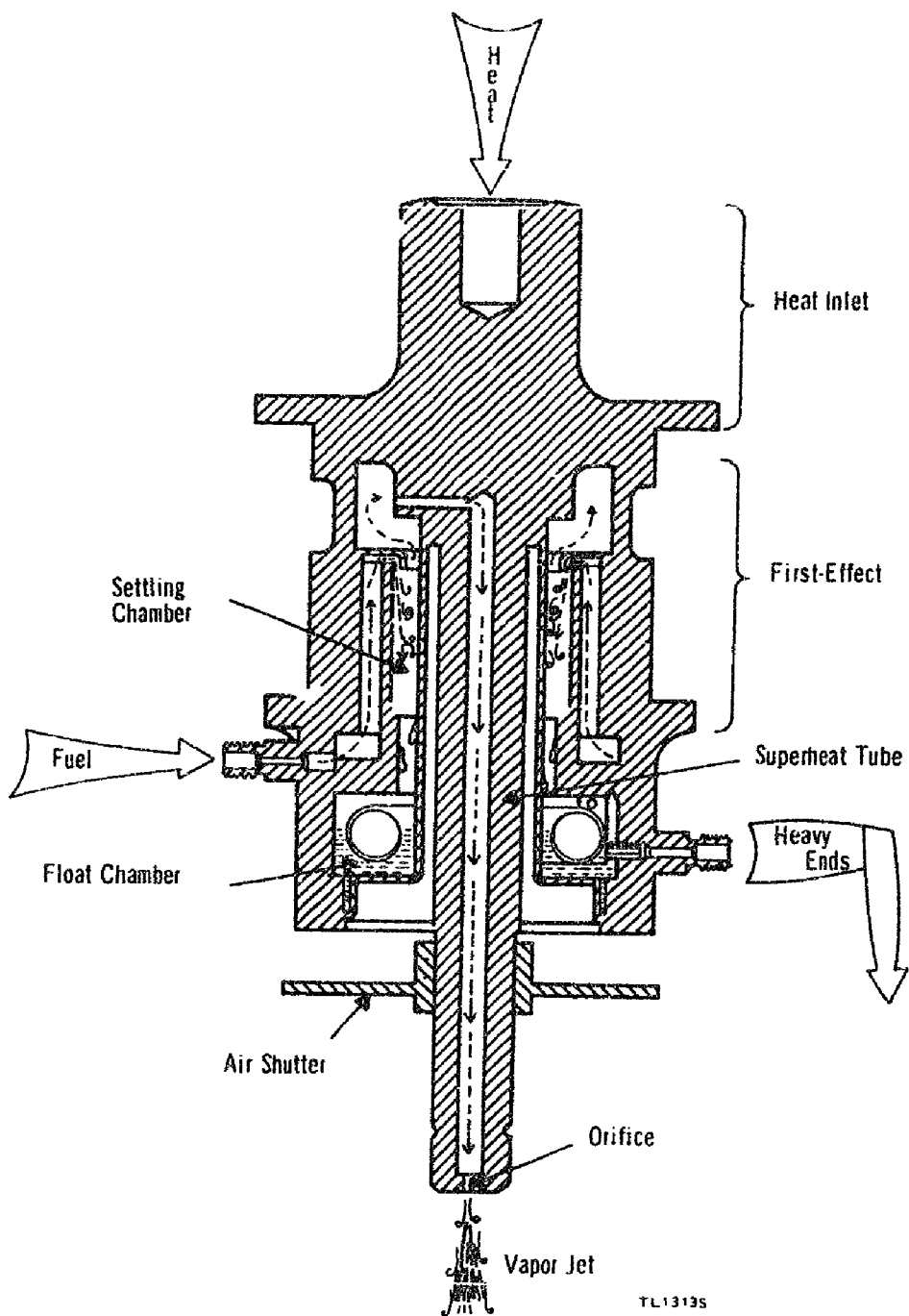


FIGURE 5 SCHEMATIC DIAGRAM OF VAPORIZER FUNCTIONS

- 4) A coaxial float construction integral with the settling chamber will minimize the condensation of "light ends" in the rejected fuel.

The above changes should not adversely affect reliability, and some should improve performance. The utilization of a single heat-source does limit the flexibility of vaporizer operation; that is, the nominal temperatures of these parts will be correct at only one firing-rate. However, the added complexity of an additional, independent heat exchanger is not worth the trouble for a generator which will always be fired at or near full power.

The control-reference temperature sensed by the mercury-plunger system is that of the first effect. It is this temperature which determines the distillate fraction and should be most accurately controlled. The superheat function greatly lessens the possibility of liquid droplets wetting the vaporizer walls in the proximity of the discharge orifice. Apparently, it is the presence of the liquid phase and catalytic effect of the vaporizer walls on the olefins and mercaptans which leads to residue formation in the orifice.^{4,5} To keep the catalytic action to a minimum, copper and copper alloys, a natural choice for thermal conductivity and machining ease, must be avoided in vaporizer construction.^{6,7} Those parts requiring high thermal conductivity are made of 1100F and 6061 aluminum alloys, the latter containing only 0.25 percent copper. The use of a free-machining alloy such as 2017 or 2024 is questionable, as the copper content is about 4 percent and resistance to corrosion is lower.

4.2.3.3 The Injector, Burner-Head and Radiant

A compound injector of conventional design was built

from 6061 aluminum. The initial construction of the Venturi and mixture plumbing is relatively heavy-walled, because thermal requirements and techniques for preheating have not been established. Hopefully, it will be possible to reduce the weight of these parts at a later date. The injector should be capable of supplying a stoichiometric gasoline-air mix at about 0.5-inch water-column, with a 25 psig vapor source. Because system pressure-drops have not been established, orifice size and pressure are subject to change. A major portion of the injector pressure-head is available to overcome the pressure-drop in the exhaust manifold and vaporizer heat-exchanger.

Gasoline-air mixture proportion is controlled by an air shutter. The setting for maximum efficiency is relatively critical in typical burners, and will change with ambient temperature and altitude variations. Adjustment procedures are simple--Orsat analysis indicates peaked combustion efficiency when exhaust-port flame just disappears--or, one may peak the thermoelement output. In the event of misadjustment, it is better to be lean than rich in mixture proportions (as will become more apparent in subsequent discussion); hence, a relatively high-pressure vapor source is required in order that sufficient combustion-air "reserve" be provided.

The approach to the combustion zone is defined by two distinct features, a set of flow baffles and a burner-head gridwork. The baffles have two functions:

- 1) They assure a laminar mixture-flow at the approach to the gridwork, and
- 2) They help apportion the mixture for an es-

entially "flat" (as opposed to a parabolic) velocity distribution behind the gridwork.

These precautions help assure the greatest flame-front stability from maximum firing-rate to extinction. The Méker gridwork is made of high-conductivity material and of the proper dimensions to produce quenching,⁸ should the flame front attempt to recede into the ports. In addition, the port velocity-gradients⁸ exceed flame-speed at the nominal firing rate when proper mixture adjustment is made. Under these conditions, operation occurs with a lifted flame-front, anchored only at the gridwork periphery. Mixture temperatures in the gridwork ports are then insufficient for the formation of lead salts, which would otherwise deposit in these passages and eventually make it impossible to supply sufficient combustion air to maintain output power.

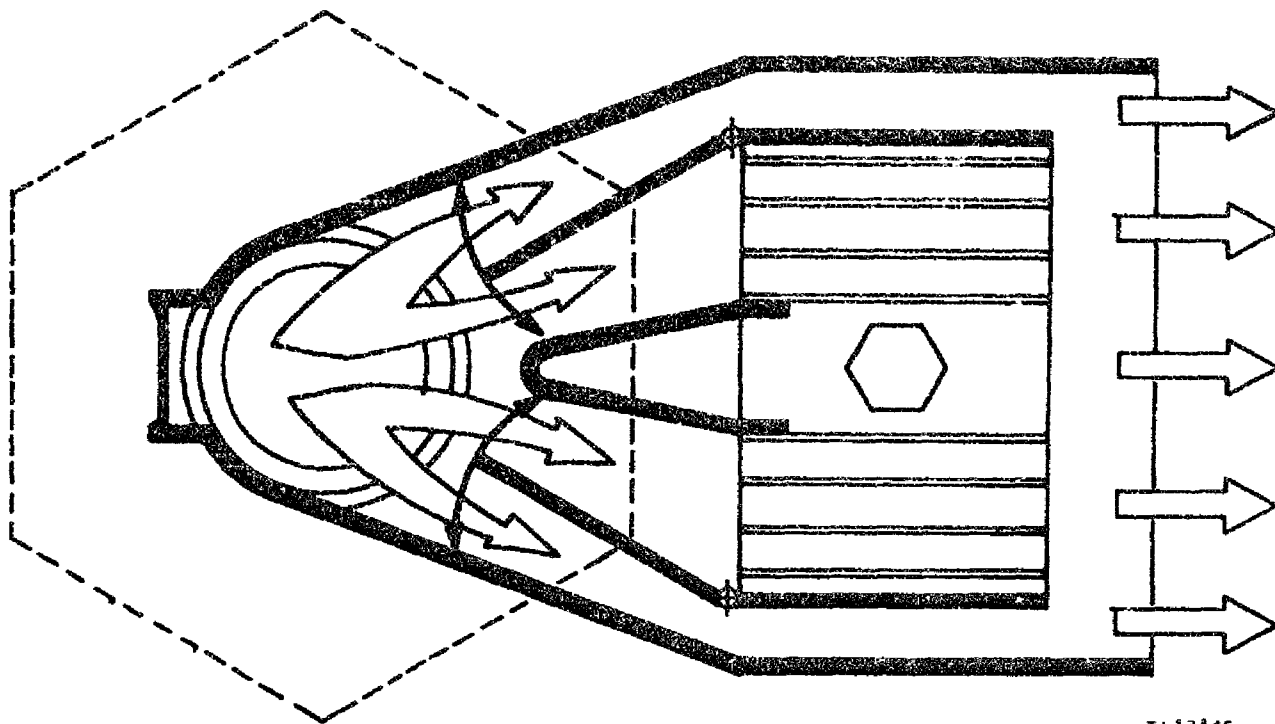
The combustion zone is surrounded by a radiant composed of Inconel screens. Radiant proportions and porosities are adjusted by trial-and-error means for a compromise between thermoelement flux-distribution and pressure-drop. Heat transfer is relatively efficient in the typical burner. The maximum efficiency at which any type of simple, non-recuperative burner could operate is limited by the thermoelement hot-shoe temperature; in this case, about 900°C. The exhaust-product enthalpy at 900°C would permit an efficiency of about 61 percent. In practice, it is not feasible to work the heat content to this degree, and an exhaust-product temperature of about 1100°C is expected, which limits efficiency to about 50 percent. Measurements of typical systems indicate that 85 percent, or better, of the latter figure will be obtained. That is, 43 percent of the heat in the fuel will be transferred to the thermoelement hot-shoes at 900°C.

It should be mentioned that an atmospheric burner does not react kindly to preheated air.⁹ That is, attempts to obtain substantial improvements in efficiency by air preheat will, to the contrary, adversely affect burner performance. A major difficulty is the loss of ability to entrain air. For example, a typical gaseous injector will only be able to produce about one-half the pressure head at 450°C mixture temperature (in the port gridwork) than it can at room temperature. Also, flame-front stability is more difficult to achieve--it becomes more difficult to quench without introducing excessive pressure-drop--and in the extreme, mixture preignition is encountered. A further consideration peculiar to the proposed burner is that the increased flame-speed would make it more difficult to operate in a "lifted" mode.

4.2.3.4 Exhaust Manifold, Butterfly, Heat Exchanger and Starting Burner

Details for most of these parts have not been fully worked out. It is anticipated that the exhaust manifold will be built of insulated Inconel sheet. A fitting will permit insertion of the starting burner, whose flame impinges upon an extension of the vaporizer heat-exchanger. After vaporizer warm-up, the burner is withdrawn from the fitting and is used to ignite the mixture in the manifold. The flame will flash through the top of the radiant and establish at the gridwork, after which the radiant is capped and the fitting is closed.

The proposed arrangement of butterflies and heat exchanger is shown in Figure 6. Exhaust products entering the manifold at the left are routed partially around the heat exchanger by the butterflies. The butterfly stems are linked to one another, and driven through a gear-and-lever train by a mercury-actuated



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FIGURE 6 EXHAUST MANIFOLD, BUTTERFLIES AND HEAT EXCHANGER (PLAN VIEW)

plunger. Control sensitivity is in the order of 10°C, by design, from a fully-open to fully-closed position.

A firing rate of about 5000 BTU/hr. is anticipated for the starting burner, but will be affected by two factors:

- 1) The warm-up time of the vaporizer, and
- 2) The noise level of the starting burner.

The developmental starting burner currently under consideration is of the atomizing type and requires pressurized air. Because of the relatively simple heating requirements and limited operating time, fuel-tank air-pressures should not be difficult to maintain. Alternate burner types can be considered, should the current type prove to be unsuitable.

4.2.4 Current Burner Status

Effort has been directed toward the intermediate goal of firing the burner with an electrically-heated vaporizer. A heating platen replaces the vaporizer heat-exchanger, permitting the greatest operating flexibility for testing. This approach permits the evaluation of basic burner elements--vaporizer, plumbing, burner-head and radiant--while the "auxiliary" system functions, such as starting and temperature control, are concurrently developed. Some burner parts are being duplicated, so that an additional propane-fired heat-source will be available for thermoelement testing.

Currently, the basic parts for the initial design have been completed, and a test set up with the electrically-heated vaporizer is in progress. The development of the starting burner has begun; spray-pattern tests with a commercial spray gun look promising, but modifications are being made. A commercial mercury element for vaporizer temperature control has been selected and ordered,

and construction of the control gear-train has begun. Many additional fittings and parts have been ordered--piping, gauges, pressure tanks, regulators, control valves, flowmeters, etc.-- and most have been received and are available for evaluation in the completed generator assembly.

4.3 Auxiliary Components and Control Devices

The selection of the auxiliary components and control devices will be made when the design of the converter assembly and the burner are in a more advanced stage of development.

4.4 Generator Assembly

The generator assembly will consist of the converter, burner, fuel tank, instrumentation, etc. Since the converter assembly and burner are only in an early state of development, no positive design has been established for the overall generator housing.

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5. CONCLUSIONS

The effort during this first quarter was devoted to the design of the converter, converter housing and gasoline burner. The thermoelectric converter will consist of twelve power modules each having six thermocouples. In an attempt to limit the size and weight of the generator assembly, the cold shoes will be cooled by two centrifugal fans and commercially available heat exchangers.

The burner portion of the generator will consist of a radiant, burner head, injector and vaporizer. All of these sections have been designed, and the majority of the components have been constructed.

6. PROGRAM FOR THE NEXT INTERVAL

During the next interval, the effort will be directed toward:

1. Building power modules
2. Evaluating individual power modules
3. Evaluating heat exchangers
4. Evaluating blowers and the plenum design
5. Evaluating the gasoline burner
6. Designing additional hardware for the generator housing

7. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

<u>Engineers</u>	<u>Hours</u>
R. Eggeman	34
H. Notarius	29
O. Schade, Jr.	304
H. Van Heyst	159
<u>Technician</u>	<u>Hours</u>
H. Albrecht	196

The technical background of the above listed engineers are as follows:

ROBERT V. EGGEMANN

Mr. Robert V. Eggemann received his B.S. in Chemical Engineering from the University of Missouri, Missouri School of Mines in 1952. He was employed by Sylvania Electric Products Inc. as a Production Engineer. In this capacity he worked on the development of improved methods for the production of tungsten, tungsten products, molybdenum, phosphors for lamps and television and other materials for the Electronics Industry and acted as liaison between Engineering and Production groups. In 1957, he transferred to the semiconductor area where he was responsible for the production of zone refined germanium and related semiconductor products. In 1961, he was employed by United Mineral and Chemical Corp. to set up a plant to produce zone refined germanium, single crystal silicon and related ultra-high-purity materials. In 1964, he joined RCA Electronic Components and Devices in the Chemical & Physical Laboratory for Thermoelectric Materials Development.

HAROLD NOTARIUS

Mr. Notarius received the B.S. degree in Mechanical Engineering in 1948 from Cornell University and M.S. degree in Physical Metallurgy in 1963 from Stevens Institute of Technology. He holds a Professional Engineer's License in the State of New Jersey. Mr. Notarius previously worked for Wilbur B. Driver Co., Machlett Laboratories and Isotronics. His assignments included

the development of glass to metal sealing alloys and sealing techniques. He was responsible for process development, chemical and plating operations, annealing and brazing of various electronic components and assemblies. Mr. Notarius joined RCA in 1962 as a Product Development Engineer and has worked on the development of Thermoelectric modules and components. He developed the process for plasma coating of chrome oxide onto aluminum radiators for emissivity purposes. He has been responsible for the technical aspects of the plating and metallographic operations in the Thermoelectric Methods and Fabrication Laboratory. Mr. Notarius was instrumental in developing a superior type of Air-Vac couple and established fabricating techniques that resulted in higher yields, reduced cost and improved operating capabilities. Mr. Notarius is a member of the American Society for Metals.

O. H. SCHADE, JR.

Mr. Schade received the B.S. in Electrical Engineering from Rensselaer Polytechnic Institute in 1953. He joined RCA in June 1953 and was assigned to the Receiving Tube Design Group in Harrison, where he was responsible for the design and development of beam-power tubes and damper diodes for television horizontal deflection circuits. He spent considerable time on problems of heat transfer, high-voltage considerations, electron optics and frame-grid designs in receiving tubes. In July 1959, Mr. Schade transferred to Receiving Tube Advanced Development, where he was concerned with the early design and fabrication techniques on new electron devices for entertainment and industrial applications. This work was followed by investigations of magnetostrictive effects in mechanical systems. He then took part in the feasibility study and initial development of thermoelectric modules for the SNAP-10A program, where he was responsible for electrical and thermal module evaluations. Since then, Mr. Schade has designed and developed gaseous-fuel burners suitable for thermoelectric generators, and is engaged in the design of generators and study of liquid-fuel burners. Mr. Schade is a member of the IEEE, the Professional Group on Electron Devices, and Eta Kappa Nu.

HANS P. VAN HEYST

Mr. Van Heyst received a B.S. degree in Mechanical Engineering from the Higher Technical School in The Hague, The Netherlands, in 1953. From 1958 to 1961, he did graduate work at Syracuse University. Mr. Van Heyst joined RCA in 1962 and has been responsible for the design, development, and manufacturing of prototype thermoelectric devices in the power-generation and refrigeration areas. Mr. Van Heyst's most recent assignment has been as project engineer on the development of thermoelectric power modules on USAERDL Contract DA-36-039-AMC-00110(E). At present he is project Engineer on this 100 Watt T.E. Generator Contract. Prior to joining RCA, Mr. Van Heyst was employed as a Research and Development Engineer at the Carrier Corporation and was involved in the design, development, and manufacturing of a 12,000 BTU/hr thermoelectric air-conditioning system for submarines. He also gained valuable experience in the fluid and thermodynamic fields. He is a member of the American Society of Mechanical Engineers and while in the Netherlands was a member of the "Vereniging of Afgestudeerden van de Hogere Technische Scholen."

<p>AD _____ ACCESSION NO. _____</p> <p>Radio Corporation of America, Harrison, New Jersey 100 Watt Thermoelectric Generator H. P. Van Heyst, O. H. Schade Jr. First Quarterly Progress Report Signal Corps Contract DA-28-043-AMC-11265(E) Project No. 1E641209 D53512, Unclassified</p> <p>During this first quarter, the dimensions of the silicon-germanium thermocouples, and subsequently, of the power modules were determined. The thermoelectric converter, to be constructed from these power modules, will operate at a hot junction temperature of 885°C and a cold junction temperature of 150°C. The cold shoe temperature will be maintained by the use of forced convection cooling.</p> <p>The thermoelectric converter will consist of twelve power modules each having six thermocouples. Forced convection cooling of the cold shoes will be accom-</p>	<p>UNCLASSIFIED</p> <p>100 Watt Thermoelectric Generator</p>	<p>AD _____ ACCESSION NO. _____</p> <p>Radio Corporation of America, Harrison, New Jersey 100 Watt Thermoelectric Generator H. P. Van Heyst, O. H. Schade Jr. First Quarterly Progress Report Signal Corps Contract DA-28-043-AMC-11265(E) Project No. 1E641209 D53512, Unclassified</p> <p>During this first quarter, the dimensions of the silicon-germanium thermocouples, and subsequently, of the power modules were determined. The thermoelectric converter, to be constructed from these power modules, will operate at a hot junction temperature of 885°C and a cold junction temperature of 150°C. The cold shoe temperature will be maintained by the use of forced convection cooling.</p> <p>The thermoelectric converter will consist of twelve power modules each having six thermocouples. Forced convection cooling of the cold shoes will be accom-</p>	<p>UNCLASSIFIED</p> <p>100 Watt Thermoelectric Generator</p>
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